Development of a Reconfigurable Protective System for Multi-Rotor Unmanned Aerial Systems

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Abstract. The purpose of this study is to illustrate how the design and deployment of a minimal protective system for multi-rotorcraft can cater for changes in legislation and provide for greater use both in and outdoors. A methodology is presented to evaluate the design and development of a system which protects both single axial and co-axial rotorcraft. The key emphasis of the development presented is the scenario in which the multi-rotorcraft can fly with increased speed, including the capability of flying through windows and doors without the fear of system failure due to rotor disruption. Furthermore, the degree of autonomy the reconfigurable system should feature as well as the effects of drag and added component mass to the performance of the system is discussed.

Keywords: autonomous system, landing gear, reconfigurable system, unmanned aerial system.

1 Introduction

In recent years the amount of research and development in Unmanned Aerial Systems (UAS) has grown substantially due to the shift in investment and policy of major military industrialized nations. There are now some 100 U.S. companies, academic institutions, and government organizations developing over 300 UAS designs in the U.S. alone [1]. In 2008, the international trade association for unmanned aircraft had 1,400 members in 50 member states [2].

Reviewing the latest US UAS Roadmap 2010-2035 indicates that the military aerial strike force will equate to 50% manned and 50% unmanned aircraft [3]. This creates a large investment opportunity and the number of new Small to Medium Enterprises (SME) in the UAS market is continuously growing. Services are not only limited to the military or law enforcement agencies. The technology is also filtering down to both the hobby enthusiast and new commercial enterprises such as that of photography and video production. Forums such as www.diydrones.com illustrate the possibility, quantity and the level of maturity that the hobbyist UAS market is achieving.

Specific to the development featured in this paper we will consider the multi-rotor range of Vertical Take-Off and Landing (VTOL) UAV´s. These systems can achieve four degrees of freedom (X, Y, Z, and RZ), they also feature the ability to hover and perch.

1.1 FAA and CAA

With the growth of UAS new problems have arisen such as mid-air collisions, air space regulation, user registration, national security and health and safety. In order to deal with many of these facets the US Federal Aviation Administration (FAA), UK Civil Aviation Authority (CAA) and more specifically the European Aviation Safety Agency (EASA) created new regulations to deal with these problems. The regulations now include systems under the 7 kg bracket as illustrated in Table 1. Vertical Take Off and Landing systems are incorporated into these regulations and as such all vehicles have to be registered to fly. By definition all aerial vehicles including those found in toy shops should fall under the requirements of user and aircraft registration with the CAA within the UK airspace.

Table 1. CAA Weight Classification Table [4].

Weight Classification Group	Civil Category	Mass (kg)	Broad Military Equivalent	Civil Regulation
1	Small Unmanned Aircraft	20 or less	Micro (<5 kg) Mini (<30 kg)	National
2	Light UAV	More than 20 to 150	Tactical	
3	UAV	More than 150	MALE/HALE	EASA

As an example, the Unites States National Air Space encompasses an average of over 100,000 aviation operations per day, including commercial air traffic, cargo operations, business jets, etc. [5]. Through the addition of UAS the number of registrations and the quantity of airborne vehicles will greatly increase.

1.2 Problem Statement

The CBP accident rate is 52.7 accidents per 100,000 flight hours (the standard safety data normalization factor/the standard on which safety data is reported). This accident rate is more than seven times the general aviation accident rate (7.11 accidents/100,000 flight hours) and 353 times the commercial aviation accident rate (0.149 accidents/100,000 flight hours) [5].

Studies focused on the cause of UAS accidents illustrate the need for regulations as well as safety system development due to the high rate of human errors [6] [7].

One of the major potential hazards of multi-rotorcraft is its exposed blades. With its brushless motors rotating in excess of 9,000 rpm and the propellers, featuring sharp edges, can produce deep cuts to exposed skin. With the addition of the system flying at speeds above 3 m/s and weighing up to 5 kg this can produce serious health and safety issues.

The second issue is with the impact survivability of the system. If a multi-rotor UAV were to be deployed and the rotor would be the target of inbound objects or collisions with the surrounding architecture, the potential for a system failure is high. In order to provide a more durable and reliable system a physical protection method is required.

1.3 Deployment Scenario

Currently multi-rotorcraft are not deployed in military tactical missions abroad due to their short flight endurance and system survivability but have been found useful in law enforcement scenarios such as crowd control at demonstrations. Military research remains active due to the potential capability of the multi-rotor UAS. In law enforcement the Merseyside police force in the UK apprehended the first criminal using a Quad rotor featuring first person view (FPS) capability [8]. In this light Kent police and BAE Systems have been trialing such systems for deployment at the 2012 Olympic games in London, UK [9] [10].

1.4 Existing Protection Methods

The current method of protection which is provided in commercial systems is that of a fixed enclosure which protects the surrounding environment from the rotating blade. An example of this is found in the AR.Parrot Drone [11]. But with such a protection system only a very specific model and design of multi-rotor can be used. These commercial systems only cater for very small payloads which ultimately lead to a single choice between sensor payload or protection system.

Fig. 1. AR Parrot Drone Protective Enclosure [11].

1.5 Identifying the key Development Aspects

The key audience and consumers of these products are hobbyists, professionals and developers. The key areas to develop have been identified as:

- A system that caters for a variety of systems ranging from 3-8 rotors.
- A system that caters for a variety of different propeller and motor dimensions.
- A system that does not reduce the field of view of attached cameras.
- A lightweight system with low addition of drag.
- A system that allows the UAS to withstand impact at different angles and speeds.

2 Development Criteria

To validate the development, a weighted matrix was used to evaluate all designs and mechanisms which led to three final development routes and one final prototype. The criteria used consisted of the following:

Table 2. Criteria for the Evaluation of the Landing Gear Protection System.

Criteria	Weighting
Horizontal Impact Survivability	1.5
Mass	1.3
Vertical Impact Survivability	1.2
Modularity	1.2
Landing Stability	0.9
Multifunctional	0.9
Field of View	0.9
Simplicity	0.9
Portability	0.7
Cost	0.5
Total	10
Maximum possible score	100

Horizontal Impact Survivability

The system has to be able to survive horizontal impact at defined velocities. These velocities are initially set at 2 m/s for both axes and will be increased accordingly. A flat surface is considered for the horizontal impact.

Mass

The current limit of the landing system as a whole should not exceed 150 g.

Vertical Impact Survivability

The system has to be able to survive vertical impact at defined velocities. These velocities are initially set at 2 m/s for both axes and will be increased accordingly. A flat surface is considered for the vertical impact. The landing system should have a large contact area or contain a flexible structure to absorb the impact.

Modularity

The objective is to create a system that is not bound to one design and that the system only requires as much landing gear as it features motor and propeller combinations.

Landing Stability

The system has to have the ability to cope with landings at an angle to the surface. This maximum set capable angle is α (pitch) 0-30°, β (roll) 0-30° and the combination of both. We assume that the landing surface is flat.

Multifunctional

The system should provide the ability to reconfigure from one configuration to another rather than be providing both at the same time, thus reducing mass and drag.

Field of View

The system should provide for an unobstructed field of view for the sensor payload whilst airborne.

Simplicity

This criterion is a collection of various factors which include ease of manufacture, serviceability, ease of assembly, reduction of the number of components, passive rather than active solutions.

Portability

The system should be capable of disassembly and be back packable which means that it should fit within the standard issued backpack for infantry soldiers. The main dimensions to be considered are volume which the maximum is set at 2 l.

Cost

The more cost effective the solution the better; the current target is set at £100 with a maximum rate set at £140.

2.1 Single Axial System

The single axial rotorcraft features a system that can be attached beneath each individual motor and is controlled via a central control board. The current mass for each individual system is of approximately 60 g including mechanism drive motor. With the brushless motors running at typically 14.8 Vdc and at full thrust the simulated decrease in performance is estimated to be of 5.4% due to the addition of both mass and drag.

Fig. 2. Prototype of a Single Axial Rotor System.

2.2 Co-Axial System HALO™

For the co-axial solution the development was based around the Middlesex HALO® Co-Axial Tri-Rotor UAS [12]. Rather than re-evaluating the supporting structure of the motor attachments the system was designed in such a manner that it could be installed by replacing structural elements. The key to this is placing the mechanism in between both motors which requires a different method of a self locking mechanism. For the first iteration, all three landing gears together weigh approximately 327 g. Running the motors at 14.8 Vdc and with full thrust capability this would result in an estimated decrease of simulated performance of approximately around 4.9% due to drag increase.

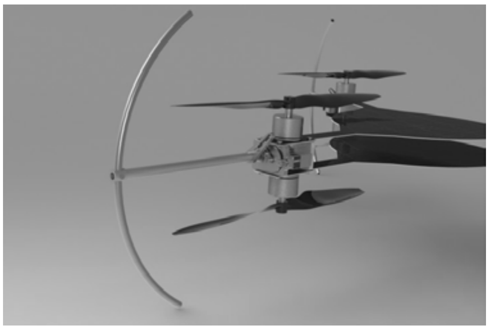

Fig. 3. Prototype Co-Axial Rotor System.

2.3 Mechanism Design

To reduce the overall count of components involved and make the system inherently strong a self-locking mechanism is required for both designs. This mechanism has to also require low amounts of torque to reduce the operating power. The advantage of the mechanism is to provide an effective landing platform as well as rotor protection. Thus reducing mass, increasing the capability of stronger impact resistance and reducing the volume of components.

2.4 Control Infrastructure

The system is controlled via a microprocessor which is operated either independently through height measurement, linked to the remote operator or in conjunction with the flight operating system. The microprocessor will primarily operate the individual motors but also verify if each motor is in the locked position according to the prescribed condition of flight or take-off and landing. One autonomous method to do this would be to feature a height measurement sensor and consequently define the status of the system. The second method is that of remote user control which dictates what position is required. The final solution is used in conjunction with the flight processing unit which can evaluate uncontrolled flight and decent, i.e. in case of an interruption in the signal. What still needs to be reviewed is what part of the system requires more protection in case of uncontrolled descent. Is it the expensive sensor payload, such as thermal imaging cameras or is it the UAS itself. The costs of individual multi-rotor systems are illustrated in Table 3.

Table 3. Cost of Typical Small Multi-Rotor UAS.

Brand	Version	Price (US$)
X3D	UFO	1,367
Draganfly	X4	8,495
	X6	19,999
	X8	32,165
Microdrone	Md4-1000	25,000
Mikrokopter	Basis L4	1,208
	Basis Hexa	1,654
	Basis Okto	2,068

3 Structural Performance

The structural performance is evidently one of the main factors of the design and this is where the majority of optimization can be achieved to reduce the overall mass by identifying the factor safety of individual components. The prototypes developed where tested using Finite Element Analysis (FEA) simulation before manufacture. These prototypes were then evaluated using an impact pendulum test-rig to simulate different velocities and impact energies and compare them with the FEA results. The mechanism itself proved to be successful but the surrounding shroud requires further development in order to guarantee repetitive quantitative results due to deflections.

4 Aerodynamic Performance

The aerodynamic effects of rotating blades were not taken into consideration in the simulation, as the main objective was to compare the amount of drag produced by the new additional components relative to the original existing frame. This provides early estimates of the additional drag, which when added to the additional mass will illustrate the overall reduction in achievable performance. The motor and blade combination used for the simulation is that of AXI 2826-14 and EPP 1045 propellers.

The simulation was conducted at an overall laminar air flow of 8 m/s relative to the components.

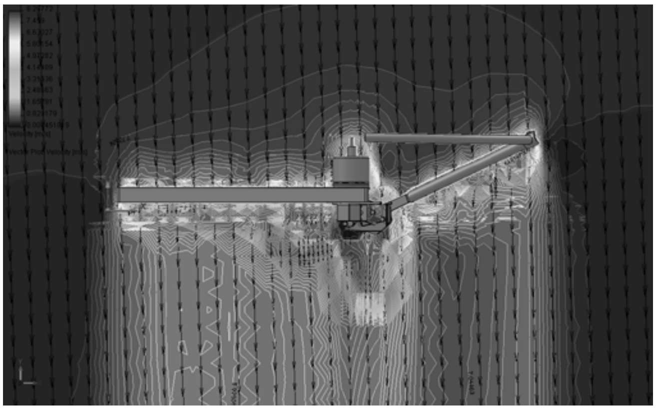

Fig. 4. SolidWorks Airflow Simulation (light areas illustrate reduced air speed).

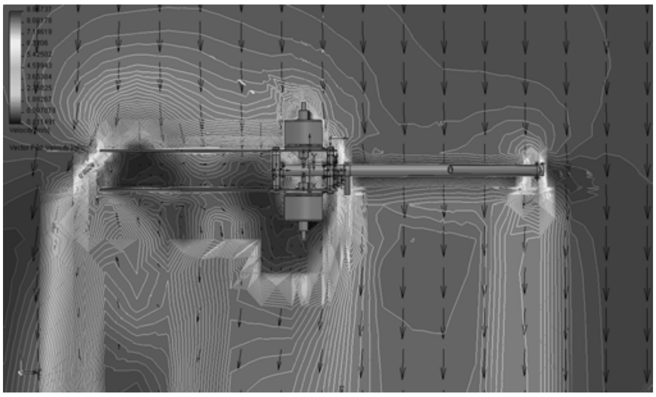

Fig. 5. SolidWorks Co-Axial Simulation (light areas illustrate reduced air speed).

5 Conclusion

The system developed provides a benchmark from which further development can be achieved. Illustrated in this paper is a demonstration of a prototype which functions to its required ability, but is only at its first iteration. Further development can lead to other methods in the way the system functions. Areas to be further reviewed are the aerodynamic performance as well as the reduction in additional mass. A system such as this can provide for a greater variety of deployment scenarios, i.e. confined urban environments, capable of coping with inbound objects and out of range descent. The possibility of bringing this into a commercial context is being currently reviewed.

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